Research on Bus Passenger Safety in Frontal Impacts

Hiroyuki MITSUISHI, Yoshihiro SUKEGAWA,
Fujio MATSUKAWA
Japan Automobile Research Insutitute
Shungo OKANO
Japan Automobil Manufacturers Association Inc.
Japan

Paper Number 287

Abstract

Guidelines with regard to the body strength of buses have been drawn up in Japan. We now pass to the second step in research to assure the greater safety of bus crews and passengers by launching a study on further reduction of collision injuries to bus occupants. As a way to reduce such passenger injuries, our focus is the optimization of energy absorption, the arrangement of equipment on the passenger seat back, the seat frame construction, mounting and so on. The study was conducted using an experimental method together with FEM computer simulation.

The findings from a sled impact test simulating a seat in a bus in a frontal collision are stated as follows.

1. Further consideration should be given to the present conventional ELR two-point seat belt.
2. One way to reduce passenger injury is to optimize the space between seats.

This report proposes measures to reduce passenger injuries based on the experimental approach employed and introduces a computer simulation model and the like now under development.

1. Introduction

Japan faces a grim situation in which approximately 10,000 persons are killed yearly in traffic accidents. Investigations of safety measures to reduce the number of such fatalities are currently moving ahead in many quarters. Efforts to improve bus safety in Japan mainly focus on crash safety measures for passengers in frontal collisions. In 1997, the guidelines were worked out to measure quantitatively the effectiveness of passenger protection measures for a large bus by crash testing[1)2)]. At this time, further ways to achieve more effective large-bus occupant protection are under investigation.

As a second step to assure the greater safety of bus occupants in a frontal collision, we are working on passenger protection, focusing on the installation conditions of various equipment attached to the seat and seat back. Here we report a series of investigations and propose measures to reduce passenger injuries based on sled impact experimental testing.

2. Bus accidents in Japan

2.1 Bus driver and attendant

Virtually all drivers sustaining more than serious injuries did so due to the reduction in survival space[3)4)]. More than 50% of bus attendants meeting with this level of injury were not seated, given the Japanese custom according to which the attendant converses with the sightseeing guide and passengers en route. Measures to reduce injuries to the driver and attendant aim to preserve survival space, and call for seat belts to be equipped and worn as effective steps so that buses built with greater safety reach the market.

2.2 Passenger injury situation

Figure 1 shows the correlation with the bodily injury location when a bus passenger sustains an injury or dies in an accident. The seats are not classified according to location, but most passengers seated in the first row were injured by the partition, while around 50% of those seated in the second row or further back were injured by hitting the seat back in the row in front of them.

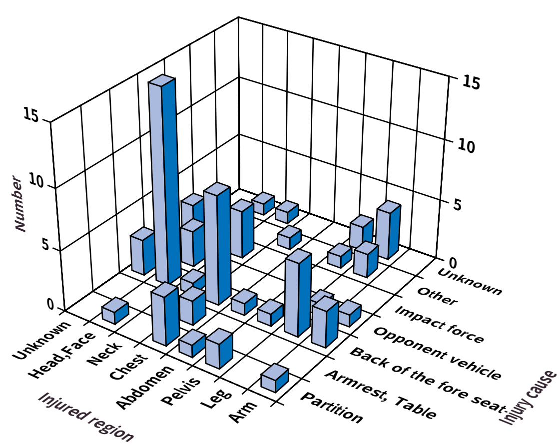


Fig. 1. Location at which passengers sustain injuries in frontal bus collisions[4)]

For the passenger, a bus must be a pleasant, safe way to travel. It is very important to pursue studies with the presumption that passengers should not be injured even in an accident. From Fig. 1 it is clear that more than 50% of the passenger injury cases result from striking the partition or seat equipment inside the bus. Thus, ways and means to reduce the injury level from impact with these interior parts are crucial.

Based on the above reports, our attempt to achieve greater safety for bus passengers first of all involved sled impact experimental tests simulating passenger seat action in a bus crash and the development of a computer simulation model. In the following, we describe the series of sled impact tests conducted.

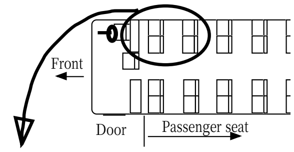
3. Sled impact testing

The parameters of the sled impact tests herewith described include seat installation spacing, seat belts (ELR 2-point types), and seating posture. Test results were used to verify the computer simulation model now under development.

3.1 Sled test method

In the tests, a sled simulating a bus passenger cabin (partition: service box, first- and second-row seats) is launched at high speed, and the force of impact on various parts of a seated dummy (Hybrid III) is measured. Interior parts mounted on the sled include the so-called service box (a box located in front of the first row of passenger seats equipped with a refrigerator and other functions), and first- and second-row seats at the time of a collision. The following test parameters were used: ELR 2-point types seat belt (wear or non-wear); arrangement of interior parts (two types: 360-mm space between service box and first-row seat cushion and first- and second-row seat interval of 860 mm as standard; or 100-mm longer); dummy seating conditions (three types: standard seat posture, reclining seat posture, and side-leaning posture); and sled launching conditions (two types: target speeds of 25 and 35 km/h). Items used in the measurement were force of the impact on various dummy parts, sled acceleration and a high-speed video camera.

Fig. 2 shows the test situation. Three Hybrid III dummies were used in three different sitting posture positions on the seats. Conditions were arranged so that several parameters could be measured in one test.



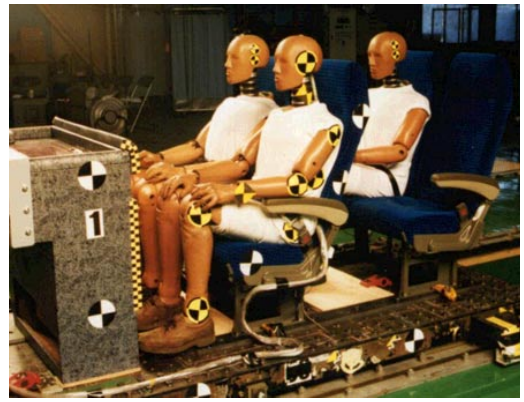


Fig. 2. Test situation

3.2 Experimental result

The sled acceleration curve employed was much more severe than in ECE R80 test conditions for a first-row bus floor. Fig. 3 shows the sled acceleration curves obtained in the sled test.

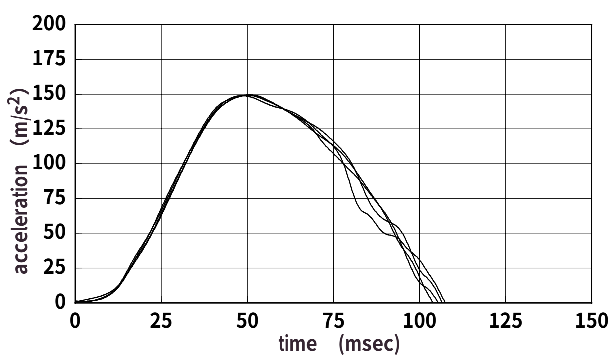


Fig. 3. Sled acceleration curves

The sled acceleration curves had a maximum acceleration of about 140 m/s^2, a duration of around 11 msec, and Delta V of about 30 km/h . The Delta V is lower than the level set by the guidelines for bus frontal collision. However, in this sled test the acceleration direction was one-dimensional. Thus, all of the acceleration on the sled was reflected in occupant reactive behavior, a very severe condition from a passenger standpoint.

Fig. 4 shows one example of such dummy behavior captured by high-speed video camera. In the test the sled

Fig. 4. Example of dummy behavior

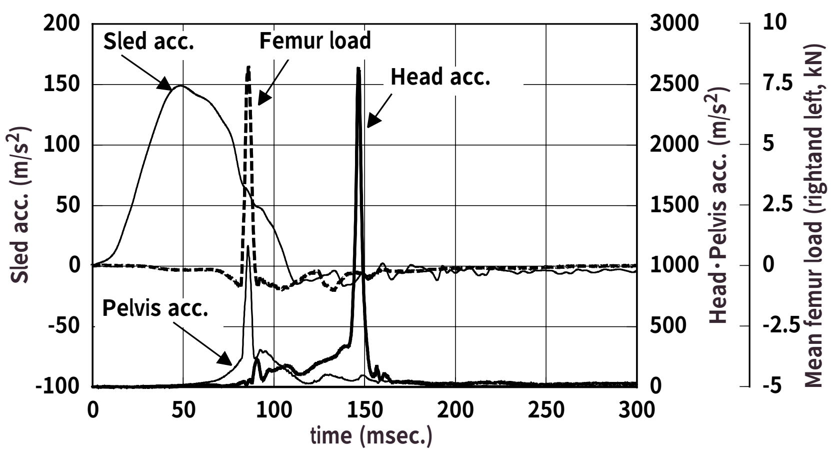


Fig. 5. Example of electric waveform data

launch is from left to right in the photo. The dummy on the left side simulates the passenger in the first row and the one on the right the passenger in the second row. The first-row dummy wears a 2-point ELR seat belt, while the one further in does not. The second-row dummy is belted in with a 2-point ELR seat belt. A standard seat interval and sitting posture are used.

The behavior of a first-row occupant wearing a seat belt is as follows. About 40 msec after the sled launch, the seat begins to move; at 80 msec or so the knees hit the service box, followed by head impact at about 140 msec. The behavior of the unbelted first-row occupant is virtually the same up to about 80 msec, but the facial portion hits the partition at about 160 msec.

Fig. 5 gives the data as an electric waveform for each part of the dummy at the time measured in Fig. 4. The data are from a belted occupant in the first row.

The peak generation time of the femur load and the peak generation time of the pelvic acceleration virtually coincide, and the head acceleration peak generation time almost coincides with the time at which it impacts the partition.

4. Greater passenger safety

Three-dimensional accelerations of a crash test can not be reproduced by a sled test. The consistently one-dimensional acceleration impact test in a sled impact test is assumed more severe for a passenger than a bus crash test. Thus, the test data can not be extrapolated to project injury levels at the time of a collision. But we made the following generalizations from comparison of the data from the set parameters.

4.1 Seat belts

Fig. 6 shows a comparison of HIC with and without a seat belt and the respective maximum values. The HIC tended to increase when the seat belt was worn, while the neck and leg values tended to decrease.

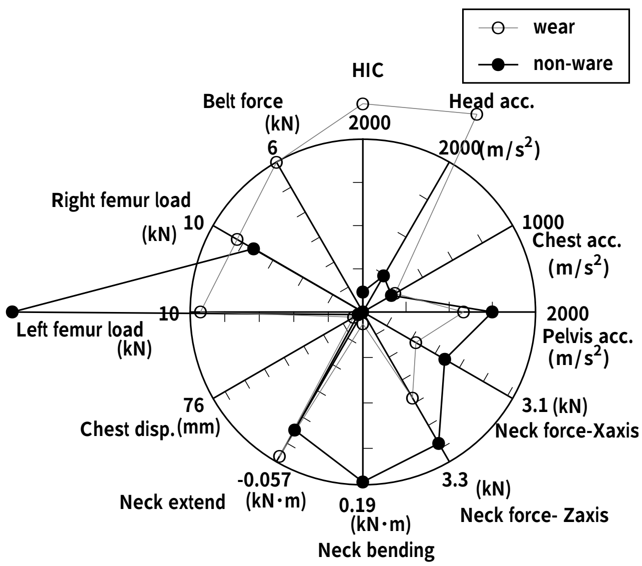


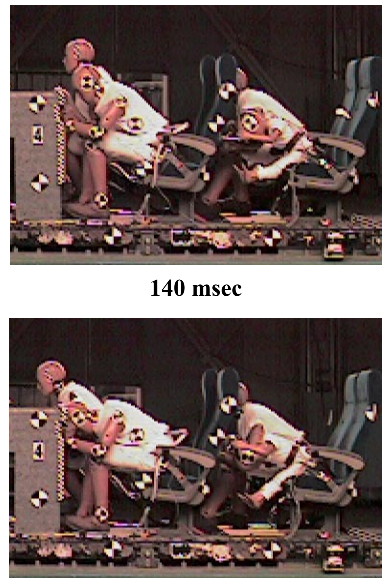
Fig. 6. Comparison of HIC and maximum values with and without seat belt (first-row occupant)

The HIC level is thought to increase because the head strikes the corner of the partition when a seat belt is worn (see Fig. 4). Since the knees hit the partition at almost the same time with or without a seat belt in place, were the seat belt to lock earlier the belt wearing effect would presumably be greater. Thus, it is important that the head will not hit the partition even if the upper torso has a rotational movement with the seat belt fastened.

To confirm the greater seat belt effectiveness by preventing the head from striking the partition and the like, a test was conducted with seat interval as the parameter. The following results were obtained.

4.2 Space between seats

Fig. 7 shows the condition in which the occupant head contacts the partition when the space between seats is increased 100 mm (i.e., by 140 and 160 msec). The occupant on the left in front is wearing a seat belt while the one in back is not. With the larger space between seats, the belted occupant's head just skims the surface of the partition; it does not collide with it as in the case of the standard seat interval. Figure 8 compares the HIC and respective maximum levels for the standard and greater spacing, respectively.



140 msec

160 msec

Fig. 7. Contact of head with partition

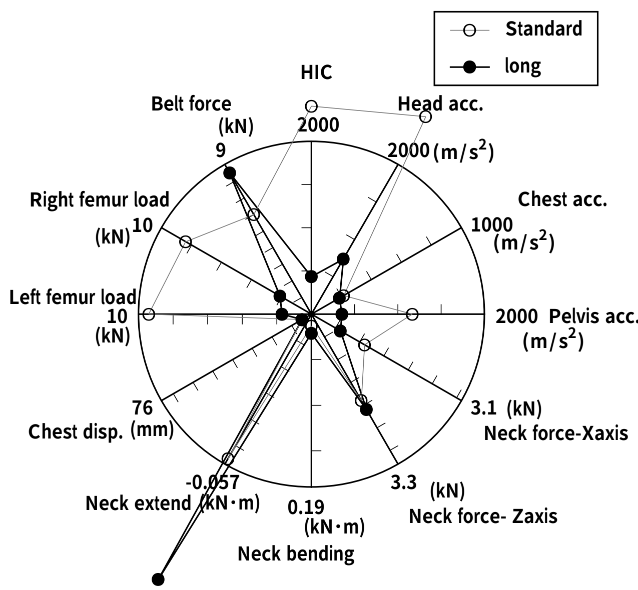


Fig. 8. Comparison of HIC and maximum according to seat interval (first-row occupant)

With more space between seats, the HIC becomes much smaller than with the standard seat spacing. Thus, the passenger's head can be expected not to hit the partition and sustain an injury. Increasing the space between seats decreases the possible injury level. However, since there may well be a greater level of injury to another part of the body (neck injury in Fig. 8) when the HIC becomes lower, it is important to investigate this matter further when attempting to obtain an overall reduction in the injury level of various body parts.

Next, we present the results of investigation on occupant posture.

4.3. Sitting posture (seat back angle)

The posture was considered for two cases, with the standard seat back angle and in the reclining position. Fig. 9 compares the HIC and maximum values for the different postures.

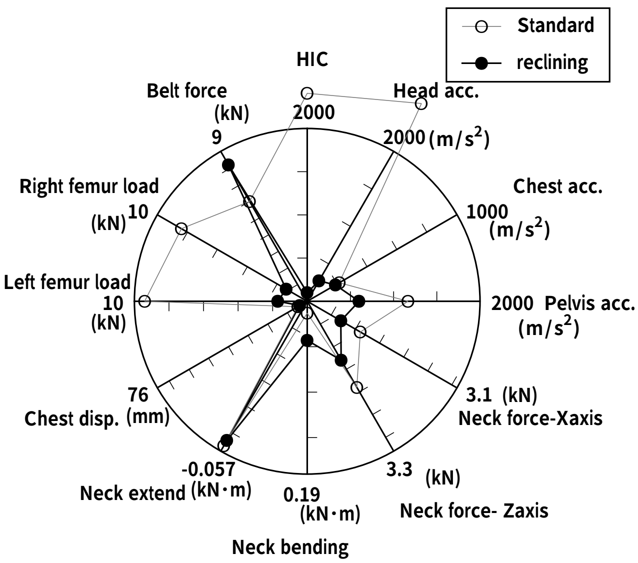


Fig. 9. Comparison of HIC and maximum values by posture (first-row occupant)

In the reclining seat posture, the HIC is smaller than with the standard posture, and the maximum values also tend to become lower without the belt load. In the reclining posture, the belt load increases and the HIC decreases. This is why, in the present test conditions, seat belt effectiveness was greater due to the reclining posture. Ordinarily, the hip-point retracts with the seat belt fastened in the reclining position, so the reason for the lower HIC and maximum values in the reclining position is that in the reclining position the belted occupant's position moves backward. As a result, as with the greater seat interval, the dummy head does not hit the partition etc. Based on this series of experimental results, we now pass to proposals to upgrade the safety of large-bus passengers at the time of collision.

4.4 Sample proposal to reduce injuries

From the results of the sled impact testing, we realized that the elimination of the possibility of a bus passenger's hitting the partition or striking the seat back in the row ahead was important for greater passenger safety. Thus, the key steps in this greater effectiveness seem to be a combination of optimal seat spacing, more appropriate seat belt lock mechanisms and optimal occupant posture.

For example, for greater safety of front-row passengers, 3-point seat belts and more space between seats could very possibly be effective. However, greater spaces between seats would mean lower passenger capacity, possibly undermining the intrinsic value of a bus. Thus, the appropriate combination of these various steps is necessary. The use of computer simulation as an experimental method would be an efficient approach, so we here introduce our model under development to be used for analysis of occupant behavior.

4.5 Computer simulation model

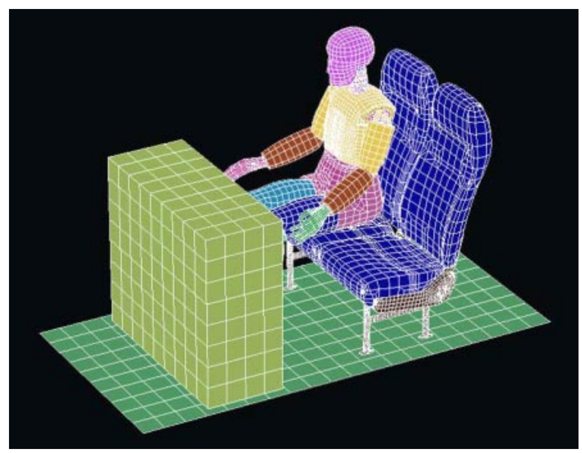


Fig. 10 The occupant behavior analysis model (FEM model)

Fig. 10 shows the occupant behavior analysis model (FEM model) presently under development. This FEM model is being developed to analyze the occupant kinematics during collision and investigate the optimal installation conditions for seat-related parts etc. in the name of greater passenger safety. We plan to use this new model along with experimental testing to move ahead efficiently to assure bus passenger safety.

5. Summary

The results of our series of sled impact tests are as follows.

1. With a 2-point seat belt fastened and the head hitting the partition, the HIC tends to increase.
2. Even when wearing a seat belt, by increasing the space between seats or using the reclining position so that the head will not strike the partition, the HIC tends to decrease.
3. Ways must be investigated to decrease the pelvic movement of a passenger wearing a seat belt.
4. Rectification of the partition and seat back characteristics, along with increased effectiveness of seat belts, is crucial.

This report covers the results of sled impact tests and has not reached the point at which they can be extrapolated to develop measures applicable to an experimental vehicle. This line of study is meant to improve the safety of bus passengers, and present plans call for further investigation by combining the FEM model under development with sled impact testing and experimental vehicle crash testing.

References

1) Y. Sukegawa, F. Matsukawa, S. Okano, Proceedings of the 30th meeting of bus and coach experts vol. 2, pp187-193 (1999).

2) F. Matsukawa, Y. Sukegawa, S. Okano, Journal of society of automobile engineers of Japan vol. 53, pp.47-53 (1999).

3) Y. Sukegawa, F. Matsukawa, JARI Research Journal Vol. 21 No. 11, pp.20-23(1999, In Japan).

4) Y. Sukegawa, F. Matsukawa, S. Okano, JSAE Spring Convention Proceedings No. 37-99, pp. 9-12 (1999).